Chlorophyll-*a* Criteria Recommendations for the James River Estuary

1   Introduction

The Virginia Association of Municipal Wastewater Agencies (VAMWA) is a statewide association of local governmental municipal wastewater treatment plant owners that work for clean water in Virginia based on sound science and good public policy. The wastewater sector has led Virginia's progress in reducing nutrient loads to the Chesapeake Bay and tidal tributaries by upgrading treatment facilities across the Commonwealth including throughout the James River basin. The James River chlorophyll-a (CHLa) criteria are of great importance to VAMWA due to the wide-ranging implications for VAMWA Member localities and their residents, local business and industry, and the environment. Historically, the task of setting CHLa criteria has been particularly challenging due to the highly subjective nature of the criteria, an overly stringent assessment method, and questionable modeling frameworks. The James River CHLa study process presents a much needed opportunity to improve the scientific basis of the criteria.

This document presents VAMWA's specific recommendations on the James River CHLa criteria and related technical/regulatory issues based on currently available information. The recommendations are based on scientific interpretation of the relationships between CHLa and designated use attainment, as reflected in the results of the James River CHLa study and related analyses. VAMWA may update these recommendations from time to time as information warrants. We appreciate the consideration of these recommendations in the rulemaking process.

2   General Recommendations

As background to specific criteria recommendations of section 3, these general recommendations address various technical and policy issues that should inform the selection of appropriate CHLa criteria.

2.1   Reference vs. Effects-Based Methods

The criteria should be based on the effects-based approach as described by Bukaveckas et al (2016), also referred to as the Empirical Relations Report (ERR). As explained in more detail by Hunley (2016) and Bell (2016), a reference condition approach would be inferior to the effects-based analysis given (a) absence of direct connection to designated use impairment, (b) heavy reliance on non-James data, and (c) association with light-saturated and nutrient-limited conditions that are probably not appropriate or realistic goals for the James River system.

2.2   Relative Importance of Individual Metrics

Harmful algal bloom (HAB) and pH effects are the most pertinent lines of evidence since those have the strongest linkages to designated use impairment. The parameters including dissolved oxygen (DO), percent CHLa contribution to total suspended solids (TSS), and the phytoplankton index of biotic

integrity (PIBI) are less useful, secondary metrics with weak and insufficient connections to the designated use impairments. Our criteria recommendations provided in Table 1 incorporate this information.

Too much emphasis has been placed on the PIBI relationships in recent discussions with the regulatory advisory panel (RAP). The PIBI is it is not sufficiently linked to designated use attainment to support regulatory applications. It is based on water quality reference conditions (see comments above) and its use leads to circular reasoning regarding management actions to improve water quality. The logic is considered circular because PIBI's desired water quality conditions (nutrient limited and high light conditions) are established *a priori*. Moreover, the demonstration that selected phytoplankton metrics have a statistical variation between nutrient or light-related bins is insufficient to conclude that aquatic life uses are or are not met. This would require information on the potential for actual harm in terms of food web impacts, toxicity, effects on higher trophic levels, etc., and the PIBI has not shown to be a useful indicator of such effects.

Another consideration is the dominant effect that water clarity has as a determinant of PIBI scores. The related management implications are that nutrient reductions alone seem unlikely to improve water clarity enough to affect the PIBI metrics as suggested. The PIBI is derived from Chesapeake Bay-wide datasets, including data from areas that have much higher light transparency than the James River estuary. Several natural factors contribute to higher rates of sediment resuspension in the James River estuary, and therefore tend to reduce PIBI scores. These factors include hydrodynamics, more extensive shoals relative to the channel width, areas of high shoreline erosion rates (Hopkins and Halka, 1997), and areas of higher proportion of finer particle size in shoreline sediments (Hardaway and others, 1992). Water clarity conditions on the James are relatively insensitive to CHLa reduction at ranges being considered for criteria. This was also confirmed by modeling analyses, which do not predict substantial increases in light availability even under aggressive management scenarios. As stated by Shen and others (2016):

> Data analysis between sediment loading from the watershed…and observed TSS shows that there is a poor relationship…except the stations located near Richmond…The TSS values in the downstream of the James River are more controlled by settling and resuspension…

2.3   Relationship Between Criteria and Assessment Method Recommendations

VAMWA strongly supports DEQ's proposal (VADEQ 2015b) to replace the existing CHLa assessment method with an alternative method. As explained in VADEQ (2015a) its proposal is less biased toward non-attainment and is better matched with seasonal mean criteria derivation. The criteria recommendations provided in Section 3 are based on the working assumption that DEQ's proposed assessment method—or a minor modification thereof—will be adopted concurrently. Though the criteria and assessment method are separate regulatory concepts, they are effectively linked since their combined application provides insight into which years or assessment periods would be considered passing or failing, which itself can provide a reality check on whether they are correctly identifying high vs low bloom effect periods. If Virginia were to continue to use the current CFD assessment method or a similar method (not recommended), our criteria recommendations in section 3 would not be applicable.

2.4   Recommendations on Arithmetic vs. Geometric Mean

The best approach is to state the CHLa criteria as arithmetic means. The ERR supplemental information section provides evidence that this statistic provides a superior correspondence between CHLa and the measured adverse effects than the observed geometric means—particularly for the lower estuary. Recent evaluation of monthly means also confirmed that the arithmetic mean has stronger statistical relationship with potential effects than the geometric mean. The use of the arithmetic mean would be consistent with the method used to derive the protective ranges in the ERR.

Although the expression of the criteria magnitude as arithmetic mean is the most defensible approach, we understand that others may prefer the use of the geometric mean. In the event DEQ should select that approach, we have developed alternative criteria recommendations expressed as geometric means. These values were calculated as a conversion of Table 1 arithmetic means to geometric means using James River site specific regression equations (see Table 2 for summary of regression coefficients and statistics).   The advantage of using converted geometric means (over observed geometric means) is that the stronger association between effects and CHLa arithmetic means effects are preserved. This is considered essential to ensure the resulting criteria (if adopted as geometric means) are appropriately proportional to and protective against algal bloom effects as intended.

2.5   Use of Annual or Monthly Data to Derive Annual Mean Criteria Values

The use of monthly rather than annual data has been proposed as a means to derive seasonal mean criteria values. Our analysis of the monthly data produced similar relationships as annual arithmetic means for the lower James River (see Figure 1). Similar patterns are expected for the oligohaline and tidal freshwater segments.   We recommend that the existing ERR protective ranges (based on annual seasonal means) continue to be the primary basis for establishing criteria given the similarity between the monthly and annual approaches.

2.6   Use of Threshold Values to Establish Criteria Magnitude

It has been proposed that criteria values should be established relative to a specified percentage of effects (HABs, pH, water clarity, and DO: 10%; PIBI 50%). This approach oversimplifies the issue. Both

the relative and absolute effects levels should be considered when setting criteria. The SAP had previously considered application of fixed interpretation thresholds but decided against the approach. It was reasoned that the magnitude of the effects values (y axis) would vary according to the underlying indicator threshold chosen. One example involves the cell density effects threshold of *Cochlodinium* (which varied by orders of magnitude). Depending on the selection of this underlying threshold the resulting effects value would go up or down. The SAP interpretations are based on relative differences and apparent "break points" rather than absolute limits. We recommend that the RAP continue to view the ERR protective ranges consistent with the SAP's interpretations.

The use of absolute effects levels as supplementary information can inform the criteria magnitude, especially with metrics are that are considered very conservative indicators of potential use impairment. For example, several metrics used in the ERR analysis are conservative in that there were applied as daily values even though the underlying criteria concepts would use longer-term averaging periods. Similarly, the microcystin threshold is at the low end of the literature range for potential aquatic life impacts. In these cases, low absolute effect levels are good indications of the lack of adverse impacts, and could be used to inform the criteria magnitude.
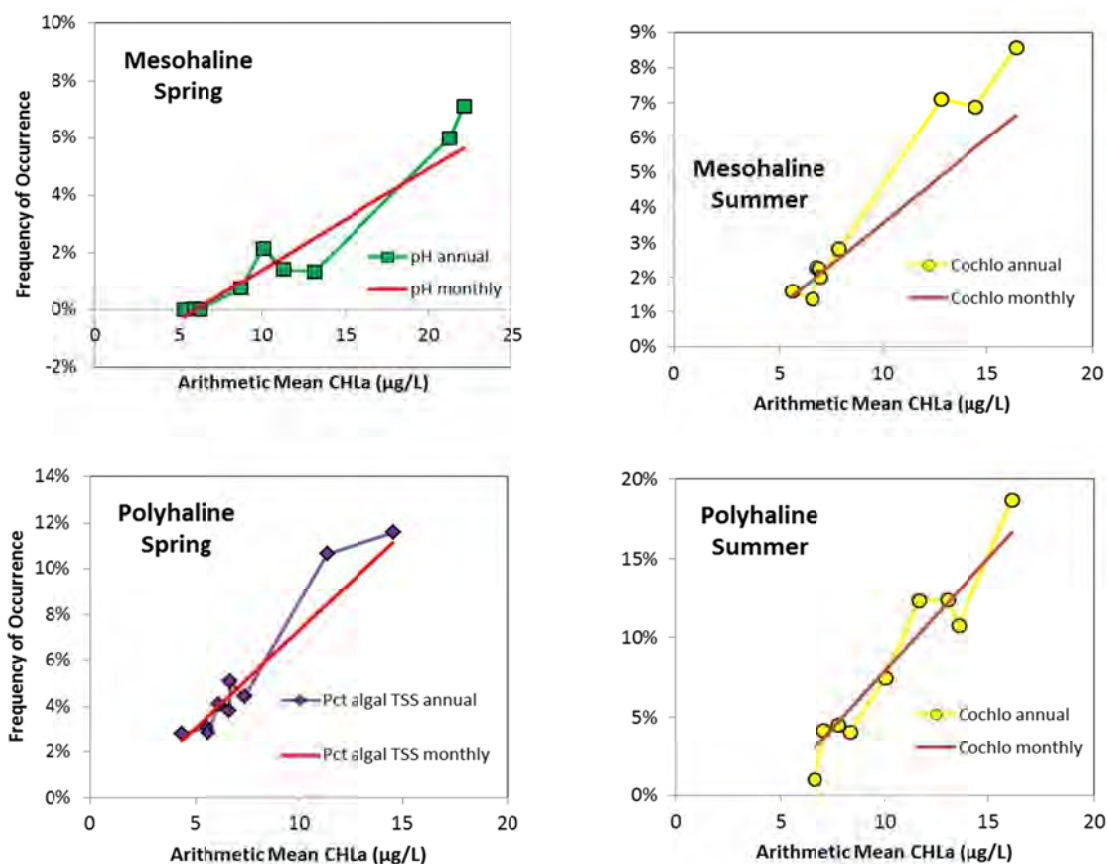
Figure 1. Comparison between annual and monthly relationships between CHLa and observed effects in the lower James River.

2.7 Determination of Whether Existing CHLa criteria are Over-Protective or Under-Protective

There are a number of factors that complicate comparisons between the existing criteria and the presently proposed protective ranges contained in the ERR. The state of the science regarding CHLa criteria development is far more advanced than what was available in 2005. As such, it is difficult to compare the two results as they vary in their technical bases. Another complicating factor is that the original criteria values were established as arithmetic means with later revisions made to assess them as geometric means. This leads to uncertainty as to for what statistic the comparisons should be made.

Given these complications and the overarching goal of using the best science, there is little or no value to attempting this comparison and, instead, the better approach is focus on updating the criteria regulations to reflect the latest scientific information. Criteria recommendations developed using this newly available information provide a better basis for determining how to protect the designated uses than a comparison between old and new criteria. The related adjustments, regardless of direction, are considered important as they have potential to affect resource protection, nutrient loading allocations, or both. Even in cases where the criteria magnitude would be unchanged it is necessary to update their scientific basis in the standards.

2.8 Importance of Full Alternatives Analysis

As expressed in the August 2016 RAP meeting, VAMWA continues to recommend that a full model-based alternatives analysis be performed prior to developing regulatory proposals for CHLa criteria. This is consistent with how the 2005 criteria were determined and with how the current James River CHLa study was designed, and is extremely important for stakeholders to understand the regulatory and economic implications of any criteria proposal by following through on the planned alternatives analysis before making any regulatory decisions. An understanding of the nutrient load-CHLa response will better inform the criteria proposal itself given the inherent uncertainty and subjectivity associated with criteria magnitude determination for CHLa and related benefits, and will potentially help Virginia avoid adopting criteria that are either unattainable (and therefore would require revision yet again or a use attainability analysis) or would represent very poor public and private investments (due to flat load-response relationships). The viewpoint that criteria cannot be informed by knowledge of load-response (the opposite of VAMWA's recommendation) is derived from a different paradigm – the toxics paradigm – under which there is much less uncertainty and subjectivity in the criteria magnitude and the response (e.g., lethality). The toxics paradigm and that viewpoint are clearly inapplicable here. Further, even small adjustments within the defensible range of CHLa criteria could have large and even unintended implications for implementation based on past experience with the James River Alternatives Analysis in 2005, which further supports the sound public policy reason for considering alternative analysis results in the decision making process.

3 Specific Criteria Recommendations

VAMWA's recommendations for seasonal average CHLa values are summarized in Table 1 by season and segment. Many of these values are consistent with the upper end of the defensible ranges shown in

Table 5 and summarized in Figure 17 of the ERR. However, there were some exceptions as described below. Also refer to Bell (2016) and Hunley (2016) for additional technical support and details.

The application of the upper end of the protective ERR range for most criteria values is justified by the following factors:

A.   The upper limit has been determined to be defensible in the ERR.

B.   The incomplete status of the criteria derivation, assessment methodology, and modeling precludes a determination of the level of management effort and related costs needed to bring the James River into CHLa attainment. Adopting criteria values lower than the upper limit at this time poses an unquantified risk of incurring higher control costs than would otherwise necessary to meet the Commonwealth's water quality goals.

Table 1. Summary of Recommended CHLa Seasonal Mean Criteria

James River Segment	Spring				Summer			
	Existing CHLa Criteria (ug/L)	Recommended Criteria Value Arithmetic Mean (ug/L)	Alternative Criteria Value Geometric Mean (ug/L)	See note	Existing CHLa Criteria (ug/L)	Recommended Criteria Value Arithmetic Mean (ug/L)	Alternative Criteria Value Geometric Mean (ug/L)	See note
Tidal Fresh Upper	10	10	8	#1	15	37	18	#6
Tidal Fresh Lower	15	19	16	#2	23	37	34	#7
Oligohaline	15	18	12	#3	22	22	21	#8
Mesohaline	12	22	10	#4	10	13	7	#9
Polyhaline	12	15	12	#5	10	12	8	#10

Notes on specific criteria recommendations:

#1: SAP analysis did not recommend a CHLa range due to lack of observed effects. Existing criteria recommended as a conservative measure.

#2: Criteria recommendation is consistent with stated SAP upper range for pH.

#3: Criteria recommendation is consistent with stated SAP upper range.

#4: Criteria recommendation is consistent with stated SAP upper range.

#5: Criteria recommendation represents an anti-degradation value. Disagree with ERR upper limit of 11 ug/l based on poor water clarity linkage.

#6: Criteria recommendation based on microcystin effects.

#7: Criterion recommendation based on middle of SAP range for microcystin and other effects.

#8: SAP analysis did not recommend a CHLa range due to lack of observed effects. Existing criteria recommended as a conservative measure.

#9: Criteria recommendation is consistent with stated SAP upper range.

#10: Criteria recommendation is consistent with stated SAP upper range.

Additional notes:

Alternative criteria values listed represent conversion of the specified arithmetic mean to geometric mean using James River specific regression equations (see Table 2).

Existing criteria were adopted as arithmetic means but are currently assessed as geometric means.

Table 2. Summary of Regression Coefficients

James River Segment	Spring			Summer		
	Regression Equation	R^2	n	Regression equation	R^2	n
Tidal Fresh Upper	y=0.7734x+0.0626	95	12	y=0.4965x+0.0755	99	18
Tidal Fresh Lower	y=0.8731x-0.1668	96	12	y=1.0078x-2.881	100	18
Oligohaline	y=0.4961x+2.7414	94	14	y=0.9719x-0.3606	100	17
Mesohaline	y=0.3114x+2.9222	85	27	y=0.41x+2.1486	59	27
Polyhaline	y=0.7261x+0.8611	90	27	y=0.4565+2.8068	67	27

Where: y= geometric mean CHLa (ug/L), x=arithmetic mean CHLa (ug/L)

Data source: Monthly means from 2005-2014 (Geomean vs Arith Mean Regressions.xlsx dated 24Aug16)

3.1   Tidal Freshwater—Upper (TF2)

3.1.1   Spring

The analysis in the ERR did not reveal strong relations between CHLa and adverse effects in this segment-season, and hence did not recommend a defensible range of CHLa criteria. For example, the

ERR analysis shows no exceedance of the pH or DO metrics. The existing criterion is 10 ug/L. The seasonal average arithmetic mean CHLa values during 2011-2014 were all below this value, and it appears unlikely that this segment-season would control load allocations. For this combination of reasons, as a conservative measure VAMWA would have no objection to retaining the existing criterion of 10 ug/L for this segment season. The James River-specific regression maps this arithmetic mean value to a geometric mean of 8 ug/L.

3.1.2   Summer

The existing criterion for this segment-season is 15 ug/L. The ERR recommended a protective CHLa range of 13-21 ug/L, primarily controlled by a relation with microcystin. However, the exceedance rate of the microcystin level was still very low (~2%) at a seasonal (arithmetic) mean CHLa of 21 ug/L, and it appears that somewhat higher CHLa means would also be associated with relatively low microcystin concentrations. The highest seasonal mean CHLa observed during 2009-2014 was ~40 ug/L, and the exceedance rate of the microcystin threshold approach was about 9% in the year. Overall, this segment-season does not appear to experience CHLa-related impairment.

DEQ currently lacks a monitoring station in the lower portion of segment TF2, and is considering adding a station there. CHLa is higher in the lower portion of the segment due to proximity to the major change in James River morphology downstream of the Appomattox River confluence, where the CHLa peak occurs. Although we support the addition of a station in this region, recent evaluation of the proposed assessment method demonstrates that the additional data from the lower portion of TF2 causes computed CHLa levels to be much higher than would be computed from the existing CBP/DEQ monitoring stations. This comment is made to advise caution against setting the criterion too conservatively low based on historically observed levels, only to find that those values are exceeded when a new station is added, despite the relatively low levels of potential adverse effects demonstrated in the ERR. The ERR analysis was able to consider data from this region due to monitoring by VCU.

With this background, the recommended arithmetic mean criterion for TF2-summer is 37 ug/L, which is less than the value (40 ug/L) associated with ~9% microcystin threshold exceedance rate, and also informed by the criteria recommendation for TF1-summer (see section 3.2.2). The James River-specific regression maps this arithmetic mean value to a geometric mean of 18 ug/L.

3.2   Tidal Freshwater—Lower (TF1)

3.2.1   Spring

The ERR analysis did not indicate that this segment-season experienced high levels of potential adverse effects even during the higher CHLa seasons observed. The recommended protective range in the ERR (10-16 ug/L) was partially based on the PIBI, which we do not consider to be a valid indicator of use attainment for reasons indicated above. A relation between CHLa and pH is also displayed for this segment; however, the rate of exceedance of the pH metric was still extremely low (~2%) at the highest seasonal mean CHLa cited (19 ug/L). Overall, this segment-season does not appear to experience CHLa-related impairment. On this basis, the recommended CHla criterion is an arithmetic mean of 19 ug/L, informed by the upper end of the existing condition. The James-specific regression maps this value to a geometric mean of 16 ug/L.

3.2.2 Summer

The ERR defines two protective ranges for this segment-season. The lower of the two (27-31 ug/L) was controlled by the PIBI which we do not consider a valid indicator of aquatic life use attainment. The alternative protective range (32-43 ug/L) is considered more relevant and appropriate, particularly due to the fact that it is based on demonstrable relations with microcystin and pH. The recommended criterion for TF2 summer is 37 ug/L expressed as an arithmetic mean, which is an intermediate value of the defensible range cited for microcystin and other effects. The James-specific regression maps this value to a geometric mean of 34 ug/L.

3.3 Oligohaline (OH)

3.3.1 Spring

The existing criterion for this segment-season is 15 ug/L. The ERR analysis demonstrated that observed metric exceedance dates in this segment-season were consistently low (<10%) for all years considered, and recommended a defensible range of 7-18 ug/L. The upper end of the ERR range is informed by the existing condition, and given the lack of CHLa-related impairments, somewhat higher CHLa criteria would also be protective of the designated use. For this segment season, we recommend 18 ug/L expressed as an arithmetic mean. The James-specific regression maps this value to a geometric mean of 12 ug/L. Because this value is informed more by the non-impaired existing condition than actual impairment, it would not be considered appropriate for this segment-season to control load allocations. If the load-response analysis indicates that this segment would be considered impaired under existing conditions or control load allocations, our criterion recommendation should be revisited as it is probably more stringent than necessary.

3.2.2 Summer

The analysis in the ERR did not reveal strong relations between CHLa and adverse effects in this segment-season, and hence did not recommend a defensible range of CHLa criteria. The existing criterion is 22 ug/L. The seasonal average arithmetic mean CHLa values during 2011-2014 were all below this value, and it appear unlikely that this segment-season would control load allocations. As a conservative measure, VAMWA would not object to retaining the existing criterion of 22 ug/L for this segment season. The James River-specific regression maps this arithmetic mean value to a geometric mean of 21 ug/L. If the load-response analysis indicates that this segment would be considered impaired under existing conditions or control load allocations, the criterion recommendation should be revisited.

3.4 Mesohaline – (JMSMH)

3.4.1 Spring

The protective ranges contained in the ERR were proposed on the basis of elevated pH. Instances of high pH have been attributed to high densities and related respiration effects from the dinoflagellate species *Heterocapsa triquetra*. Continuous monitoring systems were effective in capturing these effects. The stated upper end of the protective range as arithmetic mean (21 ug/L) was considered sufficiently protective because the frequency of high pH was <10%. However, an alternative pH evaluation (Bell and Hunley, 2015) showed that the integrated pH exceedance rate for this segment

season was less than 5% in all years, even when the seasonal mean CHLa was 22 ug/L. For this reason, a small change to 22 ug/L (rather than 21 ug/L) is recommended for the arithmetic mean criterion value. The James River-specific regression maps the arithmetic mean of 22 ug/L to a geometric mean of 10 ug/L.

3.4.2   Summer

Protective ranges contained in the ERR were proposed on the basis of *Cochlodinium polykrikoides* effects and DO. The stated upper end of the protective range arithmetic mean value (13 ug/L) was considered protective on the basis of HAB response and no adjustments are recommended.   This value was associated with lower *Cocholodinium* exceedance rates, which were below the rates observed in what were considered high bloom years (i.e. 2005, 2008, and 2010) – see Figure 7 of the ERR. The James River-specific regression maps the arithmetic mean of 13 ug/L to a geometric mean of 7 ug/L.

A particular issue important to the derivation of summer CHLa criteria values to the lower estuary (for both mesohaline and polyhaline segments) was the toxicity threshold for *Cochlodinium polykrikoides* assumed in the ERR analysis.   We found this threshold value (i.e. 1000 cells/mL) to be appropriate and conservative given the factors described in Attachment #1.

The DO end point was not considered necessary to establish CHLa protective ranges for this segment season combination. VADEQ Integrated 305(b) and 303(d) Reports for years 2012 and 2014 have indicated attainment of the 30-day DO criteria for this combination.   Results for the segment for 2008 indicated 0.03% non-attainment. This result may have been affected by sampling of sub-estuaries within the segment which are known to have lower DO than the main-stem portion.   The management implication is that because the area is generally considered in attainment with assessed DO standards establishing a CHLa protective range for DO is unnecessary. As a related comment, the ERR analysis did not demonstrate the occurrence of an otherwise significant DO problem since the 5 mg/l concentration was not intended to be applied as a daily 10th percentile DO (rather as a 30-day mean).

3.5   Polyhaline (JMSPH)

3.5.1   Spring

The protective ranges contained in the ERR were proposed on the basis of water clarity. We consider the stated upper end of the protective range arithmetic mean value (11 ug/L) to be overprotective – and we recommend an upward adjustment to 15 ug/L.   Although CHLa plays a role in light attenuation, the stated range was considered overly stringent given (a) the SAV / shallow water designated use has been consistently met in recent years, and (b) water clarity is relatively insensitive to CHLa reductions compared to inorganic suspended solids. Refer to Attachment #2 for the supporting technical analysis and details. Based on those results we recommend an arithmetic mean criterion of 15 ug/L.   The James River-specific regression maps the arithmetic mean of 15 ug/L to a geometric mean of 12 ug/L.

3.5.2   Summer

The protective ranges contained in the ERR were proposed on the basis of *Cochlodinium polykrikoides* (CP) thresholds. The proposed upper limit of 12 ug/L arithmetic mean value was considered protective on the basis of HAB response and no further adjustments are recommended.   This value (12 ug/L) was

associated with lower *Cocholodinium* exceedance rates, which were below the rates observed in what are considered high bloom years (i.e. 2009, 2010, and 2012) – see Figure 7 of the ERR. The James River-specific regression maps the arithmetic mean of 12 ug/L to a geometric mean of 8 ug/L.

References

Bell, C. 2016. Comments on Empirical Relationships Linking Algal Blooms with Threats to Aquatic Life Designated Uses in the James River Estuary – version dated April 14, 2016. Comments submitted to the Virginia Dept. of Env. Quality through the James River Science Advisory Panel. 34 p.

Bukaveckas and others. 2016. Empirical Relationships Linking Algal Blooms with Threats to Aquatic Life Designated Uses in the James River Estuary. Report from the Science Advisory Panel for the James River Chlorophyll Criteria Study Submitted to the Virginia Department of Environmental Quality (VADEQ). 44 p.

Hardaway, C.S., G.R. Thomas, J.B. Glover, J.B. Smithson, M.R. Berman, and A.K. Kenne. (1992). Special Report. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia.

Hopkins, K., and J. Halka. (2007). Shoreline Sediment Erosion in the Chesapeake Bay. Chesapeake Bay Program. Powerpoint Presentation.

VADEQ. 2015 (a). Critical Review of the Assessment Methodology for the James River Chlorophyll a Criteria. 45 pp.

VADEQ. 2015 (b). Proposed Assessment Methodology for James Rived Chlorophyll a Criteria. 22 pp.

Hunley, W. 2016. Comments on Empirical Relationships Linking Algal Blooms with Threats to Aquatic Life Designated Uses in the James River Estuary (Dated April 14, 2016). Comments submitted to the Virginia Dept. of Env. Quality through the James River Science Advisory Panel. 28 p.

Shen, J., Wang, R. and Sisson, M. 2016. James River Watershed Model Responses of Phytoplankton and Nutrients to Nutrient Reduction: Scenario Simulations Using Standard Eutrophication Model. Draft report prepared for the Virginia Dept. of Env. Qual. 80 p.

Attachment #1. Factors in support of using the cell density threshold of 1,000 *Cochlodinium* cells/ml as a measure of toxicity

An important driver for the proposed protective ranges was the threshold selected to represent toxicity test mortality. The variability in observed mortality was high across species and between tests. The selected 1,000 cells/ml threshold (Figure 3 of ERR) represents the median cell density of all of the results. Because of the factors discussed below the actual effects threshold could be higher. Note that these perspectives are offered in technical support of the defined threshold being sufficiently protective. An increase of the threshold is not being recommended at this time.

a. Inclusion of isolates data

The selected threshold was considered conservative since many of the toxicity tests were conducted on isolates. Isolates are not representative of field phytoplankton community composition. Extensive phytoplankton monitoring (both for the Chesapeake Bay as a whole and recent focused sampling of Elizabeth and James) indicated that *Cochlodinium polykrikoides* was always found in the natural environment as part of a mixed assemblage. Although the species can heavily dominate those assemblages other species were always present. Other phytoplankton in the assemblages as well as other uncounted microorganisms such as bacteria, zooplankton, or viruses may have an ameliorating effect on toxicity. However, the process by which they may reduce toxicity is not well understood.

Tang and Gobler (2009) found isolates to be much more potent than bloom samples. A similar effect was found when comparing the median threshold derived from including all data and excluding the isolate results (1,025 vs 4,600 cells/ml). The issue discussed above involving a mixed community is one possible cause. Another may be that cultured organisms are not subject to the dynamic stresses imposed on phytoplankton such as osmotic / salinity, predation, and light/nutrient limitations that would occur in the field. With these stresses removed in a laboratory setting the ability of cultured organisms to express toxicity may be enhanced or magnified. Isolates may not have same characteristics as those found in the field. The longer they remain in culture the farther removed they become from being representative of wild taxa.

b. Inclusion of non-local strains

A number of the toxicity test results were drawn from the waters of New York. There is a possibility that this strain of *Cochlodinium* could be more toxic than those occurring in the James. Toxicity tests conducted by VIMS found that the Florida strain was more toxic than the

local strain. Removing the non-local results increased the median effects threshold from 1,025 to 8,000 cells/ml.

c.   Local fishery resources seem insensitive to *Cochlodinium* blooms

Available fisheries data does not indicate a serious problem is occurring in the environment of the lower James. Oyster landings in the lower James River have been above average during recent bloom years, and it is the most productive oyster resource of Virginia's major tributaries (Mann and others, 2009; Zu and others, 2012; Southworth and Mann, 2013 - as summarized by Bell, 2014). There has also been no field evidence of *Cochlodinium* induced fish kills in the main stem James River. It is also relevant that recent oyster cage deployments in the Elizabeth and James Rivers conducted by VIMS as part of this study did not indicate adverse effects which could be attributed to HABs, even when exposed to intense blooms.

In summary of the above issues, the actual effects threshold may exceed 1,000 cells/ml cell density of *Cochlodinium*.   The major implication is that the upper ends of the stated protective ranges are considered conservative when the multiple lines of evidence are considered. The proposed protective ranges for CHLa are also below those observed in high bloom years and above those in others.

CHLa criteria might reduce but not eliminate *Cochlodinium* blooms

Cochlodinium polykrikoides is an invasive dinoflagellate that has become increasingly prevalent worldwide, partly due to transport in ship ballast waters (Tang and Gobler, 2012). As a mixotrophic taxa, *C. polykrikoides* has highly flexible nutrient acquisition capabilities, and can out-compete other phytoplankton for nutrients when conditions are otherwise favorable (Kudela and Gobler, 2012). *C. polykrikoides* does not require eutrophic conditions to flourish, as its flexibility in nutrient acquisition can allow it to bloom in mesotrophic waters (Gobler, 2010). Locally, *C. polykrikoides* blooms have been shown to be favored by a variety of complex conditions related to temperature, hydrodynamics, salinity, and nutrient availability (Mulholland and others, 2009). Reduction in overall nutrient availability (and CHLa) may reduce the magnitude of *C. polykrikoides* blooms.   However, it seems doubtful that CHLa controls could eradicate blooms of this species, and the ability to affect the frequency and extent of the blooms in the James River is uncertain.

A final comment concerning *C. polykrikoides* is that it needs to be understood that the present thresholds for CHLa for the mesohaline and polyhaline summer are only applicable to this species. Continued phytoplankton monitoring is recommended to determine if the phytoplankton community changes in terms of dominant bloom species. If that occurs it would be necessary to re-evaluate the effects thresholds and CHLa relationships.

Attachment #2. Evaluation of site specific factors influencing water clarity in the JMSPH spring combination

<u>Background</u>

Water clarity has been proposed as an end point to support numerical CHLa criteria development for the JMSPH spring combination. Water clarity in the lower James River is controlled by background color, inorganic suspended solids (ISS), and CHLa. Data analysis was performed to investigate the degree of improvement in water clarity which may be possible by achieving the protective range proposed in Table 5 of the ERR (11 ug/l) for this particular combination compared to an alternative recommendation of 15 ug/l.

<u>Methods</u>

The HRSD Dataflow program (also known as CMAP) has been in operation since 2005 and contributed data to the Virginia Estuarine and Coastal Observing System (VECOS). This monitoring platform involves weekly collection of multiple water quality measurement with YSI 6600 sondes. During each monitoring cruise fixed site samples are collected at 5 stations to provide quality assurance of the probe-based measurements and to collect additional supporting information (such as Kd, lab samples for CHL, TSS, VSS, nutrients, phytoplankton samples, etc.). These fixed site collections provided a good data source to estimate site specific water clarity relationships given that data was available for light attenuation (Licor Kd), TSS, volatile suspended solids (VSS), and CHLa.

The data were evaluated as follows:

1. Data were selected for the JMSPH segment combination for the spring season (March – May) from 2005 to 2013.
2. Inorganic suspended solids were calculated as TSS (mg/l) - VSS (mg/l).
3. A multiple regression was conducted with Kd (1/m) as the dependent variable with ISS and Chla as independent variables. ISS was evaluated instead of TSS to avoid the complications of variable Chla contributions to TSS.
4. A spreadsheet model was developed to estimate the change in Kd and percent light through the water (PLW) as a function of percent reduction of ISS and CHLa. This spreadsheet model utilized the coefficients derived from the regression analysis.

Results

A significant regression relationship was found between Kd and the independent variables of ISS and CHLa (p<0.0001, n=142). Approximately 60% of the variation in Kd could be explained by ISS and CHLa. The regression equation is listed below:

Kd (1/m)= ISS (0.06894)+CHLa(0.0097)+0.7537

These coefficients indicate that water clarity was controlled primarily by background color (intercept), ISS, and weakly by CHLa.

Discussion

The analysis indicated that water clarity in the JMSPH segment was influenced by CHLa concentration. However, the analysis also indicated that ISS and background color were the dominant parameters controlling water clarity in this segment. The presently recommended upper end of the CHLa protective range for the JMSPH segment is 11 ug/l. Figure 1 below indicates that improvement expected in percent light through the water (PLW) would be 1% compared to an alternative protective range of 15 ug/l (e.g. 25% reduction from 15 to 11 ug/l CHLa). The small incremental change in Kd associated with CHLa reduction is due to its shallow coefficient (0.0097) - which is comparable to that referenced in Chapter 4 of the recent draft James River modeling report (0.0127) based on Chesapeake Bay Program data. A 1% change in PLW (i.e. a reduction of the criteria value from 15 to 11 ug/l) is considered unlikely to improve the coverage of SAV in this segment or be detectable by the monitoring program. In contrast, a similar 25% reduction in ISS would result in approximately 5 times more improvement in PLW.

Figure 1. Effect of ISS and Chla reductions on PLW JMSPH Spring (2005-2013)
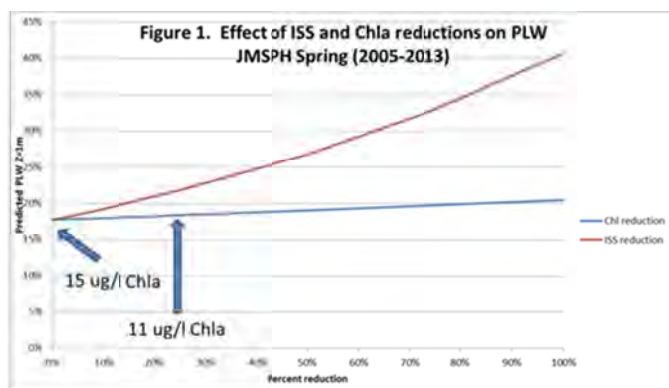
Note: Assumed starting concentrations= 12 mg/l ISS, 15 ug/l Chla

Recommendations

The upper end of the CHLa protective range for the JMSPH Spring combination (11 ug/l) should receive an upward adjustment to 15 ug/l as seasonal arithmetic mean on the basis of water

clarity. This value (15 ug/l) would represent an anti-degradation level of protection given that the highest observed seasonal mean Chla value from 2005-2015 was 15 ug/l.

Past attainment of SAV goals for this segment provides another line of evidence that the alternative recommendation for 15 ug/l would be sufficiently protective in terms of water clarity and SAV designated uses. The past two consecutive years of VADEQ integrated reports indicate that the James River polyhaline segment has met SAV and water clarity acres requirements.